COMMERCIALIZATION OF THE ADVANCED HYBRID™ FILTER TECHNOLOGY

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ABSTRACT

The theory and design of the ADVANCED HYBRID™ filter technology will be reviewed as well as the key learnings and performance data generated during three years of operating a field pilot unit at Otter Tail Power's Big Stone generating site. This performance data was used to size and design two full-scale demonstration applications of this technology, which marks the next step toward commercialization. These two applications will start-up this fall. One application is the installation of a new ADVANCED HYBRID™ filter to replace an existing electrostatic precipitator (ESP) on a cement kiln in Italy. The other application is retrofitting the existing ESP at Otter Tail's Big Stone site to an ADVANCED HYBRID™ filter design capturing the fly ash from a cyclone-fired boiler burning Powder River Basin (PRB) coals. The design of these two applications will be covered in this paper. The last section of the paper will be devoted to a discussion of the commercialization plan for this exciting new technology.

INTRODUCTION

The ADVANCED HYBRID™ filter is an air pollution control device that would allow industrial and power generation companies with stationary sources to meet the present and any proposed air emission standards for fine particulate. Unlike other particulate control devices, the ADVANCED HYBRID™ filter effectively integrates electrostatic precipitation and fabric filter technologies to provide a compact, cost effective system with fewer and more reliable components that produce superior filtration results. The net result is a system that offers the reliability of an ESP with the performance of a fabric filter. This technology is easily adapted for new installations as well as retrofits of existing ESPs.

An ADVANCED HYBRID™ pilot unit has been in operation since July 1999, filtering 9000 acfm of flue gas from the Big Stone coal-fired power plant in South Dakota. The Big Stone plant is operated by Otter Tail Power Company and is co-owned by Montana-Dakota Utilities, Northwestern Public Service, and Otter Tail Power Company. The unit has exhibited stable operating levels while cleaning the filter bags on-line and meeting particulate matter (PM) capture efficiency levels greater than 99.99%.[1]

This technology was conceived of and patented by the University of North Dakota's Energy & Environmental Research Center (EERC). W.L. Gore & Associates, Inc. (Gore) has been a technical and financial supporter of the ADVANCED HYBRID™ filter from the early stages and has been instrumental in developing the technology to its current commercial form. Today, Gore owns the worldwide rights to practice and sublicense this technology for industrial and power generation applications. It is Gore's intention to sublicense this technology to a select group of original equipment manufacturers (OEMs) around the world.

The Department of Energy/National Energy Technology Laboratories (DOE/NETL) has been a key financial sponsor of the ADVANCED HYBRID™ filter technology since its early stages of development. The DOE/NETL has selected this technology under the Power Plant Improvement Initiative to partially fund a full-scale demonstration at the Big Stone site. ELEX AG, a worldwide air pollution control supplier headquartered in Switzerland, has been granted a sublicense by Gore to practice this technology and will provide the complete system for this full-scale demonstration. The installation and start-up is scheduled for October 2002.

Another application of the ADVANCED HYBRID™ filter will be on a cement kiln in Italy. This application is also being designed and provided by ELEX AG and will start-up this September.

TECHNOLOGY

The unique configuration of the ADVANCED HYBRID™ filter promotes a synergy by combining two technologies: electrostatic precipitation and fabric filtration. The GORE-TEX® membrane filter bags are able to operate at high filtration velocities (fewer components required) and be cleaned without the normal concern of dust re-entrainment due to the close proximity of the ESP zone to the filter bags.

The internal geometry consists of alternating rows of ESP components (discharge electrodes and collecting plates) and filter bags within the collector (see Fig. 1). The inlet flue gas is directed into the ESP zone, which removes most of the entrained dust prior to it reaching the filter bags. The perforated collecting plates permit flue gas to pass through them to the filter bags. The bags are placed in a compact arrangement, adjacent to the ESP collection zone. When the filter bag is pulsed clean, the ESP plays another important role in that it effectively captures the dust cake, thereby greatly reducing the potential for dust re-entrainment onto the filter bag (see Fig. 1). The perforated collecting plate besides capturing the charged particles also serves to protect the filter bags from any potential electrical damage from the electric field. The collecting plate and discharge electrodes are periodically cleaned using typical rapping methods.

The GORE-TEX® membrane filter bags remove an order of magnitude more fine particulate than conventional filter bags and clean on-line to maintain a low, overall filter drag. This can be achieved because the microporous structure of the membrane maintains a high capture efficiency of particulate matter on its surface. All the flue gas must pass through the filter bags, which results in extremely low particulate emission levels.

The capture of the fly ash by the ESP prior to the flue gas reaching the bags and during bag cleaning enables the filter bags to operate at high air-to-cloth (A/C) ratios that are three to four times greater than conventional pulse jet fabric filters. Since the ADVANCED HYBRID™ filter can be operated at high A/C ratios, less fabric filter components such as filter bags, filter cages, and pulse valves are needed. This allows the use of higher performance and more durable components and translates into a more reliable system that requires less overall maintenance. The net result is a cost-effective system that offers the reliability of an ESP with the filtration performance of a fabric filter.

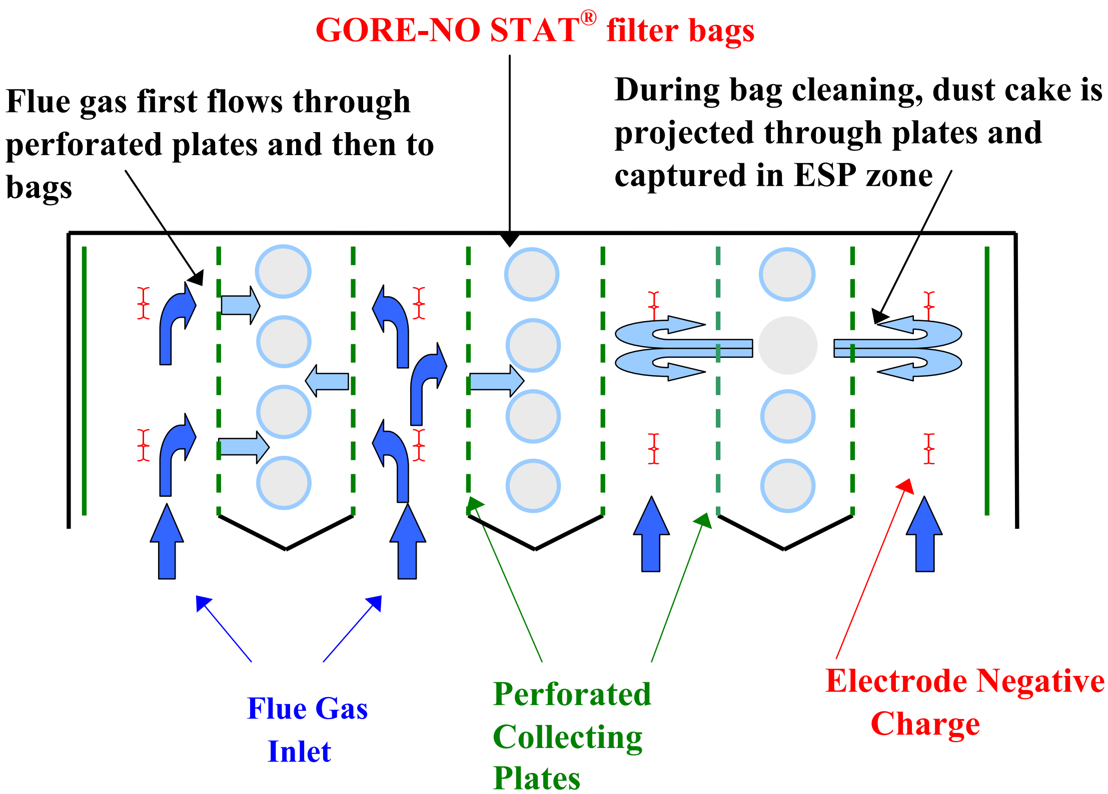

Fig. 1. ADVANCED HYBRID™ Filter Arrangement.

PILOT UNIT PERFORMANCE

An ADVANCED HYBRID™ filter pilot unit has been in operation since July 1999, filtering 9000 acfm of flue gas from a slip stream at the Big Stone coal-fired power plant in South Dakota. Several different configurations of the ADVANCED HYBRID™ filter concept have been tested and evaluated. The geometric arrangement highlighted in Fig. 1 offered the best overall performance. The pilot unit consists of four rows of eight bags.

Different filter bag constructions were operated in the field pilot unit. While several constructions performed well, the product that provided the most durability while achieving the best overall results was the GORE NO-STAT®filter bag, (GORE-TEX® anti-static membrane supported on a GORE-TEX® anti-static felt).

Different discharge electrode designs and configurations were tested. A rigid discharge electrode (RDE) was determined to be the best for this system because of its performance, durability and high degree of reliability.

The perforated collecting plate configuration, hole size and percent open area was selected to maximize the ESP particulate capture efficiency from the inlet flue gas and enable excellent capture of the dust cake during filter bag cleaning.

The pilot unit was operated almost continuously from March 2001 to September 2001 with this configuration and these components. The unit exhibited stable operating levels of 11 fpm A/C ratio on fly ash from burning various PRB coals.[2] Typical fabric filter flange-to-flange pressure differentials were maintained during this period with an average on-line pulse cleaning cycle of greater than 20 minutes. Particulate matter capture efficiency levels greater than 99.99% by EPA Method 5 have been demonstrated and are consistent with previous sampling tests.[3] The performance data is summarized and shown in Table 1.

Table 1. Pilot Filter PM Dust Loadings EPA Method 5 and 17.

Inlet (mg/m^3)	**Outlet (mg/m^3)**	**Temperature (C)**	**Moisture (% H_2O)**	**Sample Time (hrs)**	**Removal Efficiency (%)**
2677	0.21	138	12.2	4	99.992
3112	0.09	138	11.8	17	99.997
5362	0.21	140	12	15	99.996

Additional work is being completed on further optimizing the ESP components, configuration and spacing as well as the pulse jet cleaning system. Presently, the pilot unit is being used to evaluate the mercury control capabilities of this technology by injecting powdered activated carbon upstream of the collector.

CEMENT KILN APPLICATION

ELEX AG, the first OEM to sublicense this technology from Gore, has received a contract to design and build a new ADVANCED HYBRID™ filter to replace the existing ESP on a cement kiln in Italy. The system will integrate exhaust gases from a cement kiln, raw mill, and clinker cooler into one dedusting unit.

The cement plant owned by SACCI, an Italian cement producer, is located in Cagnano, Italy. The plant has used a Lepol kiln with an 1100 ton/day production capacity. An ESP was used as the dedusting device. In 2001, the plant decided to increase the capacity of the plant to 1400 tons/day by converting the Lepol kiln to a preheater kiln. At the same time, they decided to replace their aging ESP with another type of dedusting device. They selected an ADVANCED HYBRID™ filter over several options.

The ADVANCED HYBRID™ filter was designed to handle 235,400 acfm @ 300°F (400,000 m^3/hr @ 150°C). The filter will consist of three isolatable chambers, each containing 200 filter bags. The gas volume will be split between the kiln and clinker cooler in a 60/40 ratio, with approximately 24 grains/ft^3 (55g/m^3) of PM coming from the kiln and 0.9 gr/cf (2 g/m^3) coming from the cooler. There will be seven perforated plate panels per row and the plates will be seven meters high. There will be ten rows of filter bags per chamber containing 20 bags per row. The filter bag selected for this application is the GORE NO-STAT® filter bag, (GORE-TEX® anti-static membrane supported on a GORE-TEX® anti-static felt). The filter bags will be spaced down each row on 8 inch centers and will be located on 24 inch centers from row to row. The discharge electrodes and grounded perforated collecting plates will be situated between each bag row. The filter bags will be cleaned on-line with pulse headers that run perpendicular to the direction of the bag row and gas flow. The system is designed to operate at a filter bag A/C ratio of 12 fpm (3.65 m/min). The emissions level is guaranteed at 10 mg/Nm^3 with a six-year bag life.

The ADVANCED HYBRID™ filter has been constructed and the plant is scheduled to start-up this September after completing their kiln conversion (see Fig. 2).

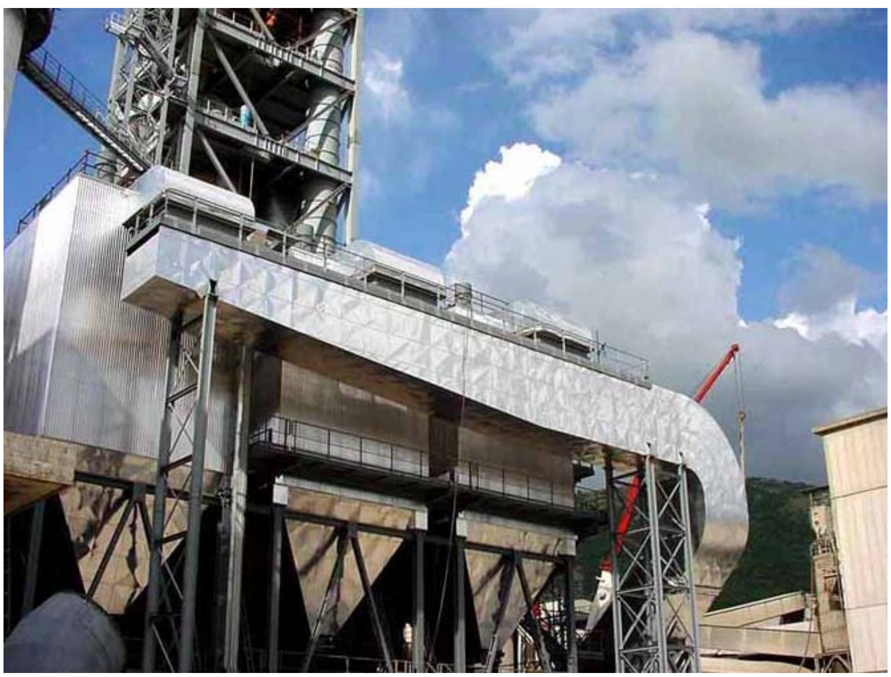

Fig. 2. Three Compartment ADVANCED HYBRID™ Filter at Cement Plant.

COAL-FIRED UTILITY APPLICATION

On October 16, 2001, the U.S. Department of Energy/National Energy Technology Laboratories (DOE/NETL) announced that it had awarded funding to support the first full-scale demonstration of the ADVANCED HYBRID™ filter technology in a coal-fired utility application.

The demonstration will take place at Otter Tail Power Company's Big Stone generating site in South Dakota. It has a scheduled start-up date of October 2002. Otter Tail Power Company, a strong supporter of innovative technologies and a believer in advancing the quality of air, has decided to convert their existing ESPs at their Big Stone site to the ADVANCED HYBRID™ filter design. Primary funding for this conversion will be provided by the DOE, Otter Tail Power Company, and the two co-owners of the Big Stone site, Northwestern Public Services and Montana-Dakota Utilities. W. L. Gore & Associates, Inc. (Gore) will also contribute supporting funds. ELEX AG is designing and supplying the overall turnkey system, with Southern Environmental Inc. responsible for the demolition and installation of the ADVANCED HYBRID™ filter system during a five-and-a-half week scheduled plant outage.

The existing ESP is a Lurgi design provided by Wheelabrator in 1975 (see Fig. 3). The design includes four main chambers each consisting of four collecting fields. Each field measures 40 ft high by 45 ft wide and 14 ft deep (see Fig. 3). The discharge electrodes are star wires mounted on pipe frame supports. These generate an ionizing field through which the flue gas must pass. The collecting electrodes are arranged in 46 rows creating 45 possible gas passages through the field. The electrodes are energized by a transformer/rectifier (T/R). The microprocessor controlled T/R converts 480 V AC to 65.3 KV DC. Collecting electrodes are rapped with a tumbling hammer arrangement while the discharge electrodes use a falling hammer/cam-drop style of rapper.

Fig. 3. Existing Four Field ESPs and ADVANCED HYBRID™ Pilot Unit at Big Stone Site. Flue gas flow is from right to left.

The Big Stone Plant's ESP will be converted into an ADVANCED HYBRID™ filter. The filter will use the same four main chambers, each containing four fields. The first field in each chamber will remain an ESP field; however, the ionizing field will not be active. The following three fields in each chamber will be updated to ADVANCED HYBRID™ filter compartments. This arrangement highlighted in Fig. 4 provides a total of 12 compartments. Guillotine type inlet dampers will be used to close off a chamber should the need arise, while outlet dampers on each compartment will be used to isolate the compartment if needed.

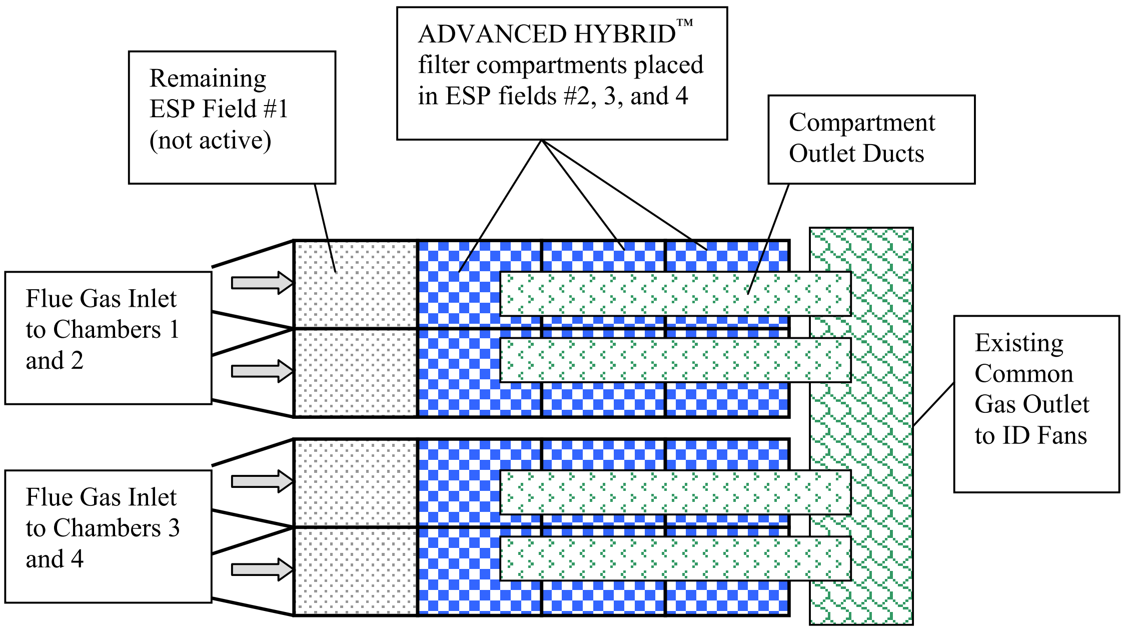

Fig. 4. Compartment Layout for Big Stone Plant (Top View).

In the outer six ADVANCED HYBRID™ filter compartments, the filter bags are arranged in 20 rows, with 21 bags per row. The six inner compartments have 19 rows of bags, with 21 bags per row. The total number of bags in all 12 compartments is 4914. They are spaced on 8 inch centers going down the row. The filter bags selected are the same ones that have been operated on the pilot unit at Big Stone and that will be used on the cement kiln application in Italy. The bags must be periodically cleaned to remove the particulate dust cake that is collected on the bag. Air headers located above each compartment receive compressed air from the existing plant air compressors. Pulse valves control an air pulse from the header to the filter bags. When the valves are opened, the pulse of air that is released initiates a shock wave, which dislodges the particulate from the bag. All of the current ID fans, ESP casing, hoppers, and dust evacuation system will remain the same.

The new discharge electrodes differ from those used in the Big Stone ESP in that they are rigid discharge electrodes (RDEs). This is a more durable construction over the previous electrodes. Each ESP zone comprises 15 RDEs positioned between the two rows of perforated plates. The perforated collecting plates or grounded electrodes are located between the RDEs and the filter bags. There are seven perforated plate panels per row. The electrodes (discharge and collecting) must be periodically cleaned to remove any buildup of particulate.

Both types of electrodes will use a tumbling hammer arrangement to accomplish this. Two rapper drive motors will be mounted outside the compartment, one for the collecting electrode hammers and the other for the discharge electrode hammers. The same microprocessor controlled T/Rs will be used to convert 480 V AC to 65.3 KV DC.

The operation of the ADVANCED HYBRID™ filter at the Big Stone Plant starts with dirty flue gas entering the four chambers, passing through the first nonactive ESP field and into each of the 12 compartments. As described previously, the flue gas first flows into a row that contains the ESP zone. Particulate matter suspended in the gas collide with the ions produced at the discharge electrodes and gain an electric charge. The charged particulate migrates to and is deposited on the plates by the electric field. The collecting plates in the ADVANCED HYBRID™ filter have perforated holes that permit the gas and any particulate that escapes the ESP to flow through the plates to the filter bags. As the gas passes through the filtration media the remaining particulate including fine particulate is captured regardless of the resistivity of the dust. All the flue gas in the system must pass through the filter bags, into the clean air plenum, and out of the compartment.

The filter bags require periodic cleaning by the pulse jet cleaning system. The pulse valves inject a high-energy pulse of compressed air into the bag and the resulting shock wave removes the buildup of particulate or dust cake on the bag. This ejected dust cake travels toward the perforated collecting plate where it is captured on the plate. The transfer of dust to the hoppers is done during plate cleaning. At timed intervals, the hammer rappers will strike the plates and dislodge any buildup of dust, which then falls into the hopper. Dust that may be re-entrained in the gas during plate cleaning will be captured by the ESP or the filter bags. The fly ash in the hoppers is then emptied and pneumatically transferred to a silo. Computational Fluid Dynamic (CFD) analysis was used in designing the ADVANCED HYBRID™ filter to determine how well the gas flow is distributed to all the compartments and within the compartments to ensure appropriate gas velocity throughout the chambers. The results of this simulation show that the gas flow is distributed evenly to the filter compartments. The reason for this even gas distribution is attributed to the space provided for the gas flow between compartments and the pressure drop across the bags within the compartment. The simulation indicates the gas flow to the back compartments previously fields 3 and 4 of each chamber, passes below the first ADVANCED HYBRID™ filter compartment and not through it. The analysis showed that there is a region below the front of field 2 very close to the bags with a higher velocity. However, the velocity is within limits based on previous experience.

The ADVANCED HYBRID™ filter is designed to process 1,824,000 acfm of flue gas from the Big Stone cyclone boiler (see Fig. 5). The inlet temperature of the flue gas will range from 250-380°F with the average temperature being around 290°F. The total pressure drop across the entire AHPC, including dampers, ductwork, and tubesheets, is 10 in WG. With an inlet loading of approximately 1.5 grains/scf, the ADVANCED HYBRID™ filter is guaranteed to yield an outlet loading less than 0.002 grains/scf. A collection efficiency greater than 99.99% is anticipated.

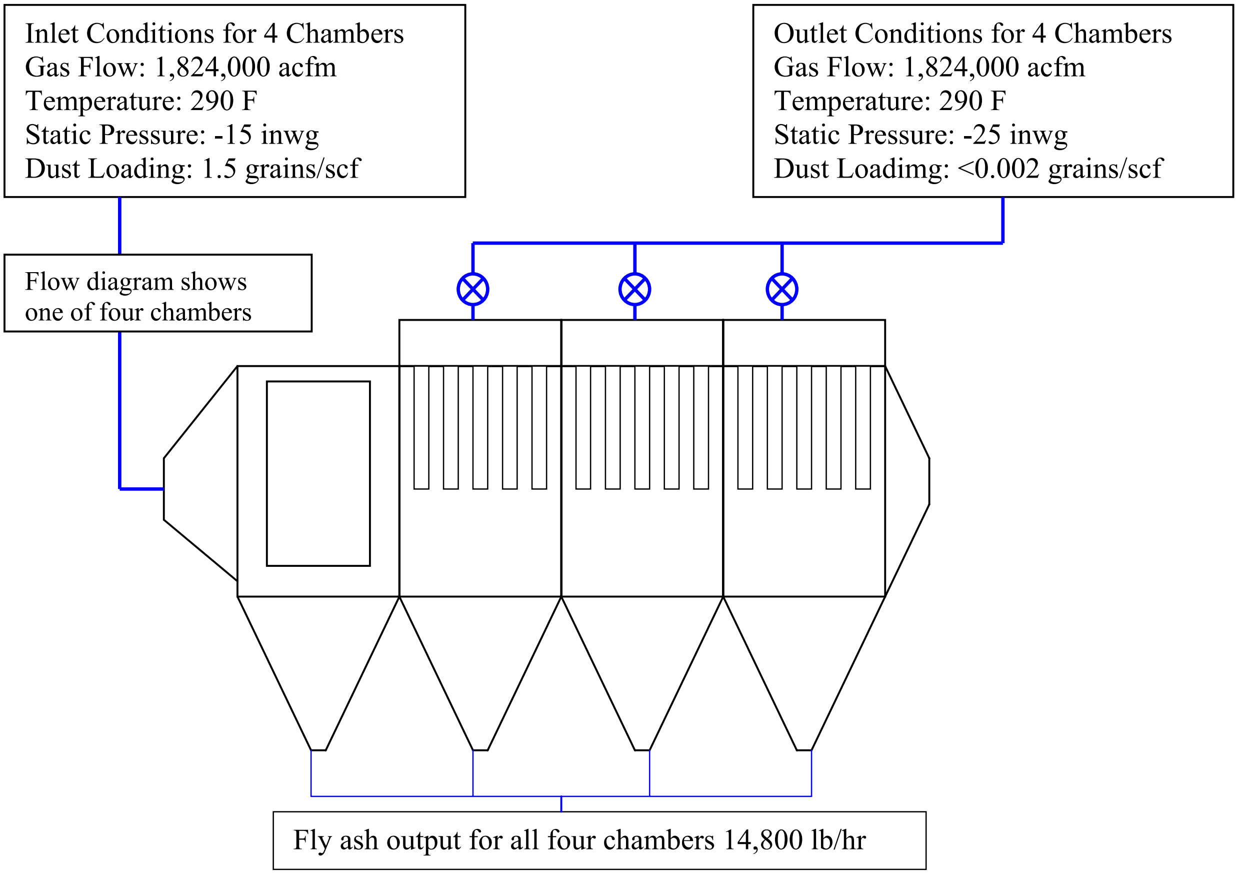

Fig. 5. Process Flow Diagram for the ADVANCED HYBRID™ Filter at Big Stone.

ECONOMICS AND COMMERCIALIZATION

The market potential for this new technology exists in markets that have a large existing base of aging ESPs that need to be replaced or converted because of pending or tighter emission controls. Two such markets are the minerals (cement industry) and the coal-fired utility market. The choice between whether to replace or convert the existing ESP is a matter of trading lower capital costs with a conversion versus the cost of a longer outage associated with making the conversion. The size and condition of the existing ESP plays a factor in this decision. The decision is a very site-specific issue. The ADVANCED HYBRID™ filter is viable in either scenario. For new installations or for new stand-alone equipment to replace the existing ESP, the pulse jet fabric filter is the next best alternative to the ADVANCED HYBRID™ filter. For retrofits or conversions of existing ESPs, the COHPAC® system is the next best alternative to the ADVANCED HYBRID™ filter.

Several new jobs have been quoted in both markets, comparing an ADVANCED HYBRID™ filter to a pulse jet fabric filter. In all cases, the ADVANCED HYBRID™ filter has been the same or lower in capital cost than the pulse jet fabric filter. Additionally, the ADVANCED HYBRID™ filter requires approximately a 20% smaller footprint and has approximately only one-third the number of higher maintenance, disposable components such as filter bags as a pulse jet fabric filter. This should lead to a more reliable, durable filter system. A recently quoted cement kiln application highlighted these advantages. This application requires only 756 GORE-TEX® membrane filter bags. This is almost 1800 filter bags less than a pulse jet fabric filter would need and the ADVANCED HYBRID™ filter would require at least a 20% smaller footprint.

Retrofit or ESP conversion jobs have also been quoted in North America and Europe comparing the ADVANCED HYBRID™ filter to a hybrid type filter, where a fabric filter is located downstream of an ESP. In those cases where the ESP was old and needed significant upgrades in order for the hybrid type filter system to function well, the ADVANCED HYBRID™ filter had the economic advantage. For example, the Big Stone conversion has a project cost for the overall filter system of $25/kW. It is anticipated that these costs will decline further as more systems are built and the design is further refined and optimized.

This technology will be positioned as an economically viable alternative to pulse jet fabric filters for new stand-alone installations and economically viable to the hybrid type filters for retrofits of existing ESPs that require a major rebuild of their inlet fields. In addition, the ADVANCED HYBRID™ filter provides a system that requires fewer components that need less space and offers superior filtration efficiencies. The technology will be sublicensed to a select group of original equipment manufacturers (OEMs) around the world. The license will allow them to practice the technology and to design and build systems in defined regions and markets.

The ADVANCED HYBRID™ filter provides many benefits, as listed in Table 2, when compared to existing particulate control technologies. It offers the reliability of an ESP with the emissions performance of a fabric filter that utilizes ePTFE membrane filter bags.

Table 2. Benefits of the ADVANCED HYBRID™ Filter.

BENEFITS	REASONS
Lower Capital Cost	Compact design, high A/C ratio, fewer components.
Lower Operating Cost	Fewer components, more reliable. Durable, high performance GORE-TEX® membrane filter bags. Comparable energy consumption costs.
Lowest Emissions	GORE-TEX® membrane filter bags.
Fuel Flexibility	The unique ESP and baghouse arrangement allows it to perform well over a wide range of plant operations.

SUMMARY

The construction of two, full-scale ADVANCED HYBRID™ filters is being completed based on excellent performance data from a field pilot unit. A new ADVANCED HYBRID™ filter located in Italy is scheduled to start up in September 2002. A full-scale demonstration unit retrofitted to an existing ESP on a coal-fired boiler located in Big Stone, South Dakota, is scheduled for completion and start-up in October 2002. This technology is easily adapted for new installations as well as retrofits of existing ESPs.

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